

The GMRT : User's Manual

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- 11 Spectrum analyser output from optical fibre for a few of the antennas, each plot showing 130 and 175 MHz. S06 (in left Figure) shows spikes (RFIs) in both channels. 40
-

Part I

Overview of the GMRT

1 The Array

The GMRT consists of 30 45 m diameter parabolic dishes spread over 25 km near the village of Khodad, about 80 km north of Pune, India. The site coordinates are:

latitude = 19 deg 05 min 48 sec North,
longitude = 74 deg 03 min 00 sec East,
altitude = 588 m.

The array consists of two main parts: a central array of 14 antennas which are labelled, C# (e.g. C00, C01, ..., C14), and an outer Y consisting of 14 km long East, West, and South arms (labelled E#, W#, and S#, respectively). There are 5 antennas on each of the east and south arms and 6 antennas on the west arm. Note that the numbering scheme is historical and is not consecutive; also, please note that there is no C07, E01 and S05 antennas (dropped due to the shortage of funds).

For an overview of the GMRT, telescope parameters, etc. please see

<http://www.ncra.tifr.res.in>

<http://www.gmrt.ncra.tifr.res.in>

and Section 4. It also gives details of the antenna, feed specifications, available frequencies, primary and synthesized beam sizes, and T_{sys} , among other parameters, are also provided. The elevation limit of the array has currently been set to 17–90 degrees (software limit), giving a declination range coverage from -53 to $+90$ degrees.

The telescope was planned to operate at 6 frequencies, but it functions at 5 frequencies, 151 MHz, 235 MHz, 325 MHz, 610 MHz, and 1000–1420 MHz. There are 4 feed systems, of which one (235/610) is a dual frequency feed (Table 1).

1.1 Protected frequency bands

The frequency bands (shown in Table 1) are protected that fall within GMRT observing bands.

Freq band		
150.05–153	MHz	ITU
230–235	MHz	Indian
322–328.6	MHz	ITU
608–614	MHz	ITU
1400–1427	MHz	ITU

Table 1: International Telecommunications Union specified Protected frequency bands.

2 The Receiver System

The GMRT receivers are designed to operate at 5 frequency bands, 150, 233, 327, 610, and 1420 MHz (the 6th, 50 MHz feed is yet to be implemented). The half-power radio frequency (RF) bandwidth (sometimes written as BW) for 150, 235, 325 and 610 MHz respectively is 40, 40, 60 and 100 MHz. The 1420 MHz band is split into 4 sub-bands centred at 1060, 1170, 1280, and 1390 MHz, each with a bandwidth of 120 MHz. Thus, the bands overlap by 10 MHz and provide continuous frequency coverage from 1000 MHz to 1450 MHz. This allows observations of HI from local gas to a redshift of about 0.4. Higher redshift HI can, of course, be detected in the lower frequency bands. The user can also choose the full band (from 880 to 1450 MHz), this is called as the bypass mode of 1420 band (see Section 4.2 for more details).

A block diagram of the receiver system (Figure 1), is shown below. RF signals are

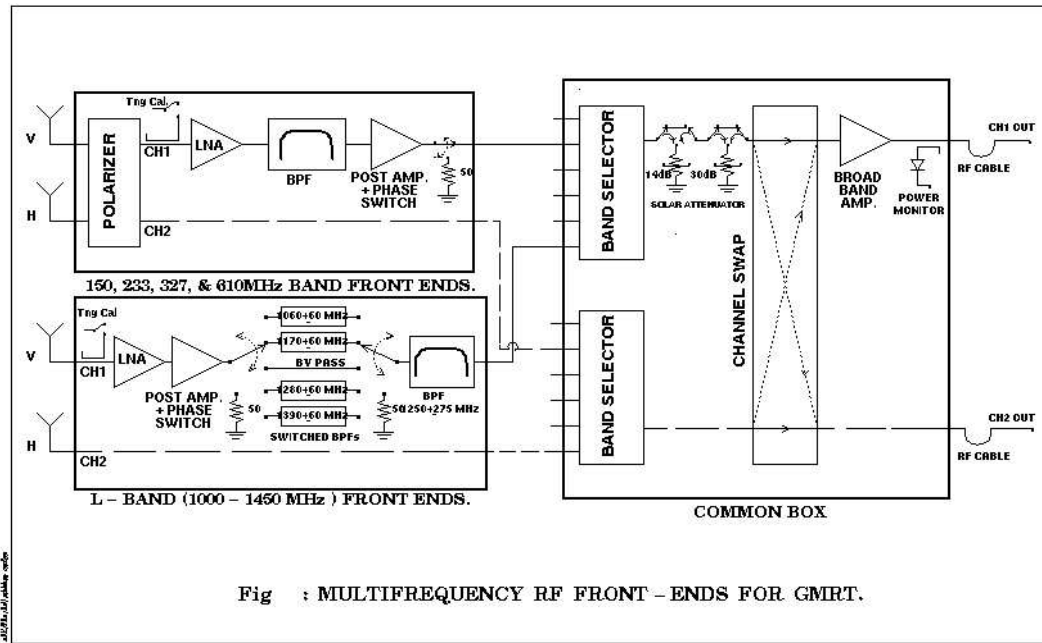


Figure 1: The block diagram of the receiver system.

received in two polarisations (called CH1 and CH2). For all frequencies except the 1420 MHz band, right and left circularly polarised signals are received, whereas for the 1420 MHz band, the signals are linearly polarised. The intermediate frequency (IF) is 70 MHz with a maximum bandwidth 32 MHz. The user can set IF bandwidth to 6 MHz, 16 MHz, and 32 MHz (see Table 2).

There are four local oscillators (LOs), the 1st and 4th LOs being under the control of the user. The 2nd LO is at the antenna base and third is in the receiver room. The 2nd LO changes the frequency to an intermediate value in order to transmit the signal

down the optical fibres into the central electronics building and the 3rd LO converts the signal back to the IF again. The 2nd LO at the antenna base is used to shift the IFs of the two polarisations to 130 and 175 MHz, so that they can be brought to the receiver room on the same optical fibre. The 3rd LO in the receiver room is used to bring the two polarisations back to 70 MHz (in the local jargon the two channels are also referred to as the 130 and 175 MHz signal). These two channels are also termed as the RR and LL Stokes parameters respectively. Two sidebands (USB & LSB) are available. This makes two IFs and each of the IFs having two channels (130 and 175 MHz) or Stokes.

The 1st LO and the 4th LO should be specified (both for the spectral line and the continuum observations, depending on the observer's requirements). The 1st LO can be set in steps of 1 MHz for frequencies from 150 to 354 MHz and in steps of 5 MHz for frequencies from 350 to 1795 MHz (GMRT sub-systems report). The 4th LO which converts the IF signal to the baseband (sometime written as BB) can be set with in steps of 100 Hz over the range 50 MHz to 90 MHz. Both the 1st LO and the 4th LO can be set *via* software.

At the antenna base, after the IF conversion, an automatic level control (ALC) system is available. This adjusts for the varying signal levels at the output of the IF and is controlled by the software. After the baseband conversion, each of the two IFs is split into two bands, the upper and the lower sideband. Here again an ALC system is available, *i.e.* at the output of the baseband converter, which adjusts for varying signal levels. For interferometric observations, the ALCs are generally on. The final bandwidth can be chosen from 64 kHz to 16 MHz in factors of 2 for each of the two sidebands.

The baseband signal is then fed into a sampler, followed by the correlator.

3 GMRT system

3.1 The Control System

Ours is an interactive control mode so that control of the telescope and its observing functions can be changed very quickly. Our conceptual model for this, therefore is a control panel, where someone dials in the desired values and pushes a button to make the whole thing go.

The “online” displays the status of the telescope (position, rates, reference position, time), the setup of various front and back ends, information on the procedure that is being run, and so on, on different screens. For each of the items on the control panel there would be a display of the current value (e.g. the exact position of the telescope at that instant).

The observer's inputs simply generates a setup that is sent to the online through the operator.

Presently, the control panel mode of program control is in its infancy. Soon, like other observatories, we would be able to do away with a machine-readable input file and this would update the variables. This would provide a way to design an experiment entirely as a “real-time” operation; instead of specifying, altering various states of the control panel; *i.e.* observer submits a file generated for his/her observations.

The following settings are usually done by the telescope operators.

3.1.1 Setting RF, LO, IF and BB.

Every piece of equipment including the telescope has one or more default setups, probably in the form of macros, that may be invoked with a simple command. Two or more hierarchies of defaults are also defined to provide complete system defaults; *e.g.* observing type defaults (line, continuum, pulsar, etc.), subsystem defaults, or special purpose defaults.

For setting the RF, LO and IF (front-end) parameters, the user needs to edit a file called `setupnew.txt`. The path being `/home/operator/set/user/user $x$ /setupnew.txt` (where $x = 1, 2, 3, 4, 5$ or m) for this file and can also be obtained from the telescope operators in the control room and run a proper program which will create control word according the setting demanded in file. Then send the control word to the antennas you need.

Also, a `cdset $x$` (where $x = 1, 2, 3, 4, 5$ or m) is the general purpose aliasing done to ease editing of the proper parameter file (`setupnew.txt`). An example of a parameter file is as follows:

This is an example of parameter file. To change the parameters you have to change the corresponding entries. The lines starting with ‘*’ are comments lines for guiding the user. More information on selected parameter is available here.

```
* this is a SETUPNEW.TXT file

* FRONT END PARAMETERS.
* select freq. of observation (50/150/235/325/610/1060/1170/1280/1390 MHz.)
235

* select solar attenuator (0/14/30/44 dB. -1 for FE Termination.)
0

* select polarization unswapped(0) or swapped(1).
0

* select cal-noise level.(E-HI(0)/HI(1)/MED(2)/LO(3) (-1 for RF OFF).)
1

* LO PARAMETERS.
* select LO freq.(100 - 1600 MHz.)
```

308

308

* IF PARAMETERS. (Default is 14 14)

* select pre_attenuator and post_gain for CH1. (0,2,4,...,30 dB)

16

2.5

* select pre_attenuator and post_gain for CH2. (0,2,4,...,30 dB)

16

10.2

* select IF band width for CH1 and CH2 respectively (6/16/32 MHz).

16

16

* select ALC OFF(0) or ON(1). for CH1 and CH2

0

0

* New parameters being added :

* enter NG in time domain (0,25,50 or 100) percent duty-cycle

0

* enter Walsh Enable(1) or Disable(0)

0

* Select the Walsh Group : Low Group(0) or Higher Group(1)

0

* BASEBAND PARAMETERS (set_para[16] onwards):

* Select the antenna group :

* [0 if all ant bb mentioned below]

* [1 if (C0 , C1 , C2 , C3 :130 MHz)]

* [2 if (C0 , C1 , C2 , C3 :175 MHz)]

* [3 if (C4 , C5 , C6 , C8 :130 MHz)]

* [4 if (C4 , C5 , C6 , C8 :175 MHz)]

* [5 if (C9 , C10, C11, C12 :130 MHz)]

* [6 if (C9 , C10, C11, C12 :175 MHz)]

* [7 if (C13, C14, SP1, SP2 :130 MHz)]

* [8 if (C13, C14, SP1, SP2 :175 MHz)]

* [13 if (W1 , W2 , W3 , W4 :130 MHz)]

* [10 if (W1 , W2 , W3 , W4 :175 MHz)]

* [11 if (W5 , W6 , E2 , E3 :130 MHz)]

* [12 if (W5 , W6 , E2 , E3 :175 MHz)]

0

```

* Select Base BANDWIDTH in KHz (16000/8000/4000/2000/1000/500/250/125/62)
16000

* Select BB Gain (0/3/6/9/12/15/18/21/24)
0

* Select BB L0 (Hz) Synth # 1 Freq.(MHz) (50.0 $<=$ L0 $<=$ 90.0 $/$ step 100 Hz)
70.0000

* Select BB L0 (Hz) Synth # 2 Freq.(MHz) (50.0 $<=$ L0 $<=$ 90.0 $/$ step 100 Hz)
70.0000

* Select Map for BB L0 Synthesizer

*   Chan  # 1   Chan  # 2

* 1 -   Synth # 1   Synth # 1
* 2 -   Synth # 2   Synth # 2
* 3 -   Synth # 1   Synth # 2
* 4 -   Synth # 2   Synth # 1
1

```

and run corresponding program which creates the control word.

ONLINE has five different user control for general purpose named user1, user2, user3, user4 and user5. For example observer having control of user4 should use cdset4. It creates control words for RF, LO, IF and BB in separate files which have to be sent to the antennas and baseband systems using the following commands

```
>run set4rf
```

This will set the front end parameter according to the modification in **setupnew.txt** file. If you use cdset1 to edit the parameter file then above command would be

```
>run set1rf
```

The same thing is applicable to setting LO, and IF.

To set LO and IF use the following commands.

```
>run set4lo
```

```
>run set4if
```

Setting the baseband is quite different from setting antenna's RF, LO or IF as the baseband system itself is an ABC inside CEB. We have to define a different subarray for baseband ABC, conventionally called ABC-0 (or CEB-ABC), having its ABC ID 0. This subarray will be running all the time on ONLINE server machine and conventionally will be subarray1 (SAC1). So to change the baseband setting you have to give commands to subarray no. 0.

The baseband is having 16 MCMs, each controlling the one polarisation and its both sidebands for four antennas. If we send proper control word to MCM it switches the band width and the gain according to selection.

Use the following command to set baseband “bandwidth”, “gain” and ‘ALC’ status.

```
> stbbfile (130, 'default') # gain files (130.csv)
> stbbfile(175, 'default') # gain files (175.csv)
> stbbalc ('both','both',1) # stbbalc('130/175/both','usb/lsb/both',1/0)
> stbbwgnall (16000,0) # stbbwgnall(bandwidth,gain)
> stbblo ('70.0000','70.0000') # stbblo(lo4_1,lo4_2)
```

These commands should be run in USER0.

3.1.2 Running up correlator for recording astronomical data

(Based on a note by Dr. Jayaram Chengalur)

Correlator has it's own control software which also talks to ONLINE software over computer network. Few programs have to be run from correlator control computer in beginning of observation session. Then onwards control goes to ONLINE software. Only a few commands it takes to change the source, start **das**, stop **das** and stop the whole observing session.

For data acquisition there are two more computers involved (**mithuna** - For USB & **mithunb** - For LSB) which talks to correlator control PCs (**corracqa** - For USB, **corracqb** - For LSB and **corrctl** - For delay tracking and fringe stopping) over the network. It creates a shared memory in it and takes the data from correlator control PC put it in shared memory. Anyone can attach to that shared memory and get the data to display it according to his/her convenience and to record on disk.

• INTRODUCTION:

A number of new correlator data acquisition modes are now available for test. These modes include:

1. Full stokes (in either USB or LSB),
2. 256 channels in RR and LL (in either USB or LSB) for all baseband bandwidths 16 MHZ or smaller
3. identical data being piped through both halves of the correlator (either for possible SNR improvements, as routinely used elsewhere, or for testing)
4. In addition of course, the old "Indian Polar" mode continues to be supported.

There has also been a substantial change in the way in which users initialize and reconfigure the correlator and das software. Rather than having to consistently edit several text files on several different PCs and supply consistent command line options, users now run a single program that guides them through a menu. This program runs on the ONLINE machine ("shivneri/lenyadri") and produces a parameter file

("temp2/data/corrsel.hdr"). Wrappers running on shivneri/lenyadri read this file and will initialize/reconfigure the correlator as appropriate for the selected observing mode. Information required for configuring acq30, dlytrk etc is also taken from this same file and transferred to appropriate locations by dassrv. This entire operation of transfer of parameters is transparent to the user.

Step by step instructions for running the new modes, looking at the data in real time, or offline, and converting to FITS follows:

• **INSTRUCTIONS FOR RUNNING THE NEW CORRELATOR MODES:**

1. log in to corracqa, corracqb, corrcctl as observer, chose the "d" ("dvl") when prompted for which software system to use. (This sets the paths and environment variables appropriate for the new "development" software. NB: if there are any shared memories floating around from the older das versions, you will need to delete them).
2. login in to mithuna and mithunb as observer and chose "d" when promoted for which software system to use. (Again, this sets the paths and environment variables appropriate for the new "development" software. NB: if there are any shared memories floating around from the older das versions, you will need to delete them).
3. login into shivneri/lenyadri as observer, and cd to /home/observer/dassrv-dvl If you want to initialize the correlator, run
`> corr init` on *shivneri/lenyadri* (This will run corr_config and newdly_config on the corrcctl PC).
4. Choose the observing setup by running `> corrsel` on *shivneri/lenyadri*

(This will setup the file /temp2/data/corrsel.hdr, which contains information on how you want the correlator configured. corrsel allows a menu based selection of the observing mode, integration time, clkssel etc.

At the moment, the following modes are predefined in corr_sel:

The names are hopefully self explanatory.

In addition, you can configure a vast number of modes by editing the DPC_MUX and MAC_MODE fields in the corrsel.hdr file.

The valid MAC_MODE values are RRLl RRRL and RR

The valid DPC_MUX values are any of the strings:

```
IndianPolar, UsbPolar, LsbPolar, UsbCopy, LsbCopy,      /* new modes */
AllU130, AllU175, AllL130, AllL175,

arar\_arar, alal\_alal, brbr\_brbr, blbl\_blbl,          /* historical */
aral\_brbl, aral\_alar, brbl\_blbr, arbr\_albl,
```

	Corr_Mode
0	IndianPolar
1	UsbPolar
2	LsbPolar
3	UsbHighRes
4	LsbHighRes
5	UsbCopy
6	LsbCopy
7	AllU130
8	AllU175
9	AllL130
10	AllL175

Table 2: Correlator Modes

Again the names should be self explanatory. In addition, the mode can be a string of the form dpc_abcd, where 0 ≤ a,b,c,d ≤ 3. A mode of the form dpc_abcd means that the dpc mux sends channel a data to where channel 0 data normally goes, channel b data to where channel 1 data normally goes and so on.)

NB: In the UsbHighRes and LsbHighRes modes the DPC_MUX is set to UsbPolar and LsbPolar respectively. However the MAC_MODE will defer for the HighRes and Polar modes.

- reconfigure the correlator to the selected mode. To do this type

```
>corr reconf
```

on *shivneri/lenyadri*. PLEASE NOTE THAT IF YOU ARE CHANGING THE MODE, IT IS NECESSARY TO DO A hltndasc AND RESTART acq30 ETC. (IT MAY BE SAFEST TO KILL AND RESTART ALL THE acq PROGRAMMES. NOT KILLING acq MAY AFFECT SYNCHRONIZATION OF THE TWO PIPELINES. MOST OF THE TIME IT SHOULD BE FINE TO KEEP acq RUNNING, AND JUST CHECK FOR SYNCHRONIZATION PROBLEMS AFTER YOU RESTART. IF THINGS ARE SYNCHRONIZED THEN FINE, OTHERWISE YOU WILL NEED TO KILL AND RESTART acq).

- start acq, acq30, sockcmd fstop, dlytrk,dassrv,collect on the appropriate machines. Note that none of the programs need command line options, but instead, as explained in the introduction, will automatically understand the selected observing mode.

NB: The acqs on corracqa/corracqb/corrcrl should be started within 1 STA cycle(i.e. 128 ms!) of each other. The easiest way to do this is:

Mode Name	Band Mask
IndianPolar	15
UsbPolar	3
LsbPolar	12
UsbHighRes	3
LsbHighRes	12
UsbCopy	3
LsbCopy	12
AllU130	1
AllU175	2
AllL130	4
AllL175	8

Table 3: Bandmask for Each Mode

- (a) export the corracqa/b/ctl window to all desktops.
- (b) go to any one desktop and align the acq windows one below the other
- (c) type "acq" in all windows (but don't type ENTER!)
- (d) hit the ENTER button in all windows in quick succession.

I agree that this is a pretty silly way to do things. A more automatic method is in the prorverbial pipeline.

7. Ask the operator to give an init and add a project from the master terminal. The bandmask while initing and adding a project should be correspond to the chosen mode.

NB: The bandmask is a bit mask with bits in the order USB130 USB 175 LSB130 LSB175

For a pure USB observation the bandmask is 3 (e.g. UsbPolar, UsbCopy, AllU130..)

For a pure LSB observation the bandmask is 12 (e.g. LsbPolar, LsbCopy, AllL130..)

For a dual sideband observation the bandmask is 15 (e.g. IndianPolar).

The actual bandmask for each mode is tabulated below:

NB: All of these modes use both halves of the correlator, so will use CMODE 3 in ONLINE.

8. start and stop scans, record as usual. Median filter can be used. as always it is upto the user to decide if s/he wants median filter or not. The maximum filter length is 128. RECORD NOW TAKES AN ADDITONAL OPTION "SELF". IF THE LAST [OPTIONAL] ARGUMENT IS "SELF" THEN RECORD WILL PUT ONLY THE SELF CORRELATIONS IN THE LTA FILE. For example.

Bandwidth (MHz)	Samp_freq (MHz)	Samp_rate (μ sec)	CLK_SEL	Channel width (kHz)	Possible IF-BW (MHz)
16	32	0.03125	0	125.0	32/16
8	16	0.06250	1	62.5	32/16 (6 ?)
4	8	0.12500	2	31.25	32/16/6
2	4	0.25000	3	15.625	32/16/6
1	2	0.50000	4	7.8125	32/16/6
0.5	1	1.00000	5	3.90625	32/16/6

Table 4: Bandwidth, CLK_SEL and IF selection.

> record TEST test.lta 8m self

will create a file test.lta with only self correlations in it.

NB: In the new modes the data is divided between the two halves of the correlator. For example in the UsbPolar mode U130xU130 and U175xU130 come in mithunb (i.e. the "ltb" file) while U175xU175 and U130xU175 come in mithuna (i.e. the "lta" file). Hence

- (a) dasmon in mithuna or mithunb will only show you one half of the data
- (b) "normalization" cannot be applied in some modes. To normalize U175xU130 one needs the U130 and U175 selfs, but both will be available only when one merges the data streams.

9. . You can merge the lta and ltb files using ltamerge. This merged file will have the complete data, and is easier for playing around with taxx.

10. The merged file can be converted to FITS using listscan and gvfits. These programs are also backwards compatable. The individual lta/b files can also be converted using these programs, but I don't seem to be able to get AIPS to understand the polarizations in a file with only RR RL or only LL LR. I think that only some partitioning produced by the VLA correlator is understood. The combined RR RL LR LL FITS file is interpreted without problem.

• In (online machine) **User0** window

>cmode 3

1 for USB, 2 for LSB, 3 for both

>tpa(11)=15

>allant

puts all 30 antennas in array

>initndas '/temp2/data/corrsys.hdr'

`>suba 4`
subarray number for which project is to be started

`>prjtit'title'`
The title for the project, upto 80 characters.

`>prjobs'Yourname'`
'TST' or Name of Observer, upto 8 characters.

`>ante 10 1 2 3 .... 10 or allant`
`>initprj(15,'PRJCODE')`
3 for USB, 12 for LSB, 15 for both

- From **User4** of online

`>tpa rf1 rf2 lo1 lo2 lo4 lo4`
Here `rf` is the frequency of the band edge (channel 0), `lo1` is the frequency of the first local oscillator, `lo4` is the frequency of the fourth local oscillator.
e.g. tpa 325 325 255 255 70 70. See Sections 4 and 4.1 for more information.

`>prjfreq`
Copy project parameters into ONLINE shared memory

`>lnkndas`
Setup the link between ONLINE and DAS.

`>gts 'srcname'`
Get source parameters.

`>sndsacssrc(1,12h)`
Position antennas to the source and begin tracking.

`>strtndas`
Start the data acquisition for the given source.

`>stpndas`
Stop the data acquisition for the given source.

`>opsacfil '/odisk/gtac/cmd/yourname.cmd'`
To open the Sacfile or Command file.

`>strtsacfil`
It gives control to the subarray controller which reads the instructions from above mentioned file (yourname.cmd).

`>stpsacfil`
Stop the command file (yourname.cmd).

- From **User0** window of online

`>cmode 3`
1 for USB, 2 for LSB, 3 for both

`>suba 4`
subarray number for which project is to be started

`>stpprj`
Stop the project.

`>hltndas`
Halts acquiring the data from correlator.

Part II

Before observing

4 Preparing for Observations

The following should be carried out before the observing session for ALL OBSERVATIONS.

1. Check GMRT specifications to choose the appropriate frequency, primary and synthesized beam sizes to match the source and the science.

	Specifications
Parabolic Reflector Diameter	45m
Focal Length	18.54 m
Physical aperture	1590 m ²
Sensitivity of single dish	0.3 K/Jy
Feed Support	Quadrupod
Mounting	Altitude-azimuth
Elevation Limits	Software Limit 17–90 degrees Hardware Limit 15–110 degrees
Azimuth Limits	Software Limit –265 to +265 degrees Hardware Limit –270 to +270 degrees
Slew rate	Azimuth 30 degree/minute Elevation 20 degree/minute
Design wind speeds (3 sec peak at 10 m height)	Operation upto 40 km/h Slew upto 80 km/h Survival 133 km/h
Size of wire mesh of reflecting surface	20×20 mm, outer 1/3 area 15×15 mm, middle 1/3 area 10×10 mm, inner 1/3 area
Maximum <i>rms</i> surface errors, at wind speed of 40 kmph	20 mm, outer 1/3 area 12 mm, middle 1/3 area 08 mm, inner 1/3 area
Tracking and pointing accuracy	1' <i>rms</i> at wind speeds of < 20 km/h

Table 5: The GMRT specifications

2. Check the latest antenna status with telescope operators to see which antennas are available and the central square and complete Y configurations to see that the *uv* coverage is adequate.

* For spectral observations fudge factor is close to 1

3. Determine the source rise/set times. At the NCRA, Pune, this can be accomplished using the utility, `tact` (see man `tact` for an explanation). At the GMRT, Khodad, the ONLINE command ‘gts’ will accomplish this, provided a source file has been created and loaded (see Appendix **Z2**). Also you can use from ‘GMRT home-page → Observing Help → For GMRT Observations’ for finding source rise/set times.

Frequency (MHz)	Type of feed
50	Half-wave dipole with linear reflector
153	Two Orthogonal pairs or dipole over a plane reflector
233	Dual concentric coaxial cavity
610	Dual concentric coaxial cavity
327	Half-wave dipole over ground plane & a beam-forming ring (Kildal feed)
1420	Corrugated horn

Table 6: Feed description

	Frequency (MHz)				
	151	235	325	610	1420
Primary Beam (arc min)	186±6	114±5	81 ± 4	43 ± 3	24 ± 2 * (1400/ <i>f</i>)
Receiver Temperature (T _R)	144	55	50	60	40
Typical T _{sky} (off Galactic plane)	308	99	40	10	4
Total System Temperature (K)	482	177	108	92	76
(T _R + T _{sky} + T _{ground})					
Antenna Temp (K/Jy/Antenna)	0.33	0.33	0.32	0.32	0.22
Synthesised Beam (arcsec)					
Whole Array	20	13	9	5	2
Central Square	420	270	200	100	40
Largest Detectable Source(arcmin)	68	44	32	17	7
Usable Frequency Range (MHz)					
Reliable	150 - 156	232 to 244	315 to 335	590 to 630	1000 to 1450
With some Luck	150 to 158	230 to 250	305 to 360	570 to 650	950 to 1450
Fudge Factor(actual to estimated)					
Short Observations	10	5	2	2	2
Long Observations*	5	2	2	1	1
Best rms sensitivities achieved so far as known to us (mJy)	1.5	0.6	0.3	0.02	0.03
Typical Dynamic Ranges	> 1000	> 1000	>1500	>1500	>2000

Table 7: Measured System Parameters of GMRT

System Settings

IF bandwidths	32, 16, 6 MHz
Baseband bandwidths	16, 8, 4, 2, 1, 0.5, 0.25, 0.12, 0.062 MHz
Polarisation swap	Swap on (1) / Swap off (0)

Table 8: Table showing IF, baseband bandwidths and polarisation swap

4. Choose a bandwidth, $\Delta\nu$ (see Table 2), from the available bandwidths and choose a sampling frequency which is twice the bandwidth (for Nyquist sampling). The sampling frequency is specified *via* the parameter, `clk_sel`, where $2 \times \text{BB} = \text{samp\_freq} = 32/(2^{\text{clk\_sel}})$ (see Table 4).
5. Determine the required time on source, τ . This is computed *via*:

$$\Delta S = \frac{\sqrt{2} k T_{\text{sys}}}{\eta_a \eta_c A \sqrt{(n_b) n_{\text{IF}} \Delta\nu \tau}}$$

where ΔS is the required rms noise (Jy), T_{sys} is the system temperature (K), and $[(\eta_a A)/(2k)] = G$ is the antenna gain (K/Jy), where η_a and η_c being aperture and correlator efficiencies respectively. A is the geometrical area of the antenna, n_b is the number of baselines, n_{IF} is the number of IF channels, and $\Delta\nu$ (Hz) is the bandwidth of each sideband (or channel width for spectral line observations).

Here, $n_{\text{IF}} = n_{\text{pol}} + n_{\text{SB}}$, where n_{pol} is the number of polarisations (2 for the GMRT) and n_{SB} is the number of sidebands. Note that the improvement in S/N by operating in double sideband mode applies only to continuum observations. The required parameters are provided here.

6. Choose a primary flux density calibrator and phase calibrator from the VLA calibrator manual. The VLA calibrator manual is also available at the GMRT site. The best sources for GMRT use will be those which are usable at all VLA arrays (*A*, *B*, *C*, and *D*). However, sources which are not acceptable as *A* array calibrators (and possibly *B*) may still be acceptable, provided the appropriate *uv* limits are adhered to. It is best not to use a calibrator which is not usable at *D* array since this will eliminate the central square of the GMRT. Decide which calibrator will be used to calibrate the bandpass. This is usually the flux density calibrator, but could be the phase calibrator for strong, low frequency sources.
7. Create a source file; the source file contains the names, coordinates, and coordinate epochs of all sources to be observed. It is usually named *via* the initials of the observer (*e.g.* ‘yourname.list’, lower case !). Only one such file is usually necessary (a master list) since the file can contain more sources than are

actually observed. The format must be exact (including spaces) and is case sensitive. Thus, it is best, when first making the file, to copy and edit one which is already in existence. The telescope operator can supply a template file (or see `astro1@lenyadri/shivneri/lenyadri:/odisk/gtac/source/★.list`). There is already a ‘cal.list’ file in regular use which includes many calibrator sources, including the primary VLA flux density calibrators. However, it does not contain all sources in the VLA calibrator manual. Therefore, it is likely that the phase calibrators will also need to be included in the user’s master list of sources. Once the source file is created in the user’s home directory, it should be copied by the telescope operator into a directory which can be read during the observing session. A sample ONLINE command for loading the file is `addlist astro1:lenyadri/shivneri/lenyadri:/odisk/gtac/source/yourname.list`.

8. Create a command file (see Appendix **Z2** in the end of this document and/or `astro1@lenyadri/shivneri/lenyadri:/odisk/gtac/cmd/★.cmd` for templates). This file contains commands for the telescope to slew to a source, track, collect data for a specified time, etc. Any of the commands in this file can also be input manually at the console during observations, but the file, when accessed, will prevent the necessity of a continuous input of manual commands. It is possible to override this file from the console; however, when started again, it will start from the beginning of the file, so some editing might be required if this occurs. Strategically, it is best to start the observing run with commands issued manually so as to monitor a calibrator and correct problems from the console level, if they occur. Once satisfied, the command file can then be invoked. A typical example of a command file can be found in Appendix Z2. Command files are usually put in the directory, *e.g.* `astro1@lenyadri/shivneri/lenyadri:/odisk/gtac/cmd/yourname.cmd` (lower case !).
9. Choose a integration time. The integration time specifies the time over which data from the source is collected, thus specifying the time interval for an individual visibility. The integration time is specified through the parameter, LTA (long term accumulator), which is an integral number of STA (short term accumulator) units, the latter being the shortest sampling time allowed by the correlator. One STA = 132.096 milliseconds, so LTA = 128 corresponds to 16.908 seconds. If a 10 minute scan is specified, there would be ~ 35 record $((60 \times 10)/16.908)$ points in your datafile.
10. Choose the BB bandwidth (see Table 2). The BB should be at least as large as the final IF width, but much larger could introduce unwanted interfering signals.
11. Choose a sideband and determine the frequency of the 1st LO. For lower sideband (LSB) operation, $\nu_{LO1} > \nu_{RF}$ and $\nu_{LO1} - \nu_{LO4} = \nu_{RF}$, where ν_{LO1} is the local oscillator frequency, $\nu_{LO4} = 70$ MHz is the IF, and ν_{RF} is the sky (observing) frequency. For upper sideband (USB) operation, $\nu_{RF} > \nu_{LO1}$ and $\nu_{RF} - \nu_{LO4} = \nu_{LO1}$. The tuning is set to match the 1st channel, not the centre of the band and

the user should note the permitted frequency increments (see Section 2). Also note that there may be other technical considerations which limit which sideband can be used at any time. The user should check with a local expert. The user can also use the programme `tune` available locally.

4.1 Spectral line observing with GMRT

This section is for users interested in spectral line observations with GMRT. Observer must be aware that GMRT always observes in the spectral line mode. The FX correlator always generates 128 channels per sideband for the selected baseband bandwidth. This is useful since one can take care of bandwidth smearing and also fixed delay effects across the band. What differentiates spectral line observations from standard continuum observations is that the local oscillator settings are important so as not to miss the spectral line which is expected at a certain frequency. For the continuum observations, one can use the default settings (see Table 9) for the desired band. Moreover, one can choose to record less than 128 channels in the case of continuum observations whereas for spectral line projects, recording data of all channels would be desirable.

For spectral line projects, the user will need to have an idea of the observing frequency and the desired bandwidths.

1. **Determining the observing frequency:** Once you know the rest frequency of your spectral line, the redshift for far Universe objects should give you the observing frequency. In case of Galactic or near Universe objects, the NRAO programme 'dopset' (available *via* usual "`source /astro/RC`") can be used to obtain the change in the rest frequency due to the earth's rotation and motion around the Sun so as to obtain the heliocentric or the local standard of rest values. Please note that online Doppler correction is not provided at GMRT - the change over an eight-hour run is ~ 1 km/s.
2. **Determining the baseband bandwidth:** The available bandwidths at GMRT are in binary steps from 62 kHz to 16 MHz. Observations with bandwidths greater than 0.5 MHz are regularly made whereas the lower bandwidths are not frequently used. You will have 128 channels spread over the baseband bandwidth that you choose. Please note that there are three choices for the IF bandwidth: 6, 16 and 32 MHz. Depending on your project, the line width will vary from a few km/s (Galactic lines) to a few hundred km/s (extragalactic lines). Select a channel width such that you have at least 2-3 channels across your expected line width. Thus '`128×selected_channel_width`' gives you a 'minimum' bandwidth required. The other point to consider now is the desired velocity coverage. This is also very project dependent. If you are trying to observe multiple transitions within your band *e.g.* while observing recombination lines, it is desirable to obtain both hydrogen and carbon lines which are separated by 150 km/s within the band. Thus, this might mean compromising your channel width. This is a subjective

decision. The third and last part is the available bandwidths at GMRT. You have to make your own decision as to which is the best combination for your project.

In the new correlator modes you could have 256 channels (see section 3.1.2 and/or GMRT home-page → Observing Help → Features in the Experimental Stage).

3. **Determining the LO settings:** Once you have decided on your observing frequency and the baseband bandwidths, you need to figure out the local oscillator settings for GMRT. For Galactic and near Universe spectral line observations, fine adjustments to the local oscillator frequencies are required for the narrow bandwidths used. For the distant Universe, these settings are more coarse since the bandwidths generally employed are large. To help you with these settings a locally developed programme **tune** is available at GMRT. The programme is user-friendly and will help you play around with the local oscillator frequencies (both for $LO1 > RF$ and $LO1 < RF$). Default settings are as follows:

```

150 MHz LO1 > RF
240 MHz LO1 > RF
330 MHz LO1 < RF
610 MHz LO1 < RF
L sub-bands LO1 < RF

```

and visualize your observing band. It also provides you with default local oscillator settings for each GMRT frequency band used for continuum observations. Please note that LO1 (the first local oscillator in electronics) has a least count of 1 MHz for frequencies < 350 MHz and a least count of 5 MHz for frequencies > 350 MHz. This translates practically to the fact that only coarse settings are possible in the LO1 whereas the fine settings have to be implemented using LO4 (the fourth LO in the electronics). Only LO1 and LO4 are under user control since LO2 and LO3 are used for optical fibre transmission from the antennas base to the receiver room. Once you have determined all the required frequencies, you can use the **Frequency Setting Calculator** on the GMRT web-page to determine the array of parameters **tpa** which are required by the correlator. The TPA array consists of 6 members namely as follows:

```

RFfreq in spec chan 1 for 130 MHz,
RFfreq in spec chan 1 for 175 MHz,
LO1for 130 MHz,
LO1for175 MHz,
LO4for130 MHz,
LO4for175 MHz

```

where 130 MHz corresponds to RR and 175 MHz to LL polarisations. Please note that $(RF_{\text{freq}} \pm LO1 = LO4)$. If you plan on dual frequency observations ie 240 MHz on LL and 610 MHz on RR (default), you will follow the explanation discussed just above. In addition to the above, depending on your baseband bandwidth you will need to tell the correlator the sampling frequency. A

parameter named CLK_SEL is required to be specified for this purpose. The **Frequency Setting Calculator** available on GMRT web-page will tell you the required CLK_SEL once you have specified the baseband bandwidth. You can also calculate it yourself as

$$2^{\text{CLK\_SEL}} = \frac{16}{(\text{baseband BW})}.$$

So if your baseband width is 8 MHz, then CLK_SEL = 1 (see Table 4).

An example will make the above easier to comprehend. Suppose we have proposed and have been allotted time for making a Galactic HI absorption measurement using GMRT. The rest frequency of the HI line is 1420.40575 MHz. Assume that the velocity correction due to the earth/Sun motion and the source velocity (computed using **dopset**) shifts the line to a frequency of 1420.505 MHz. We would like to center our band on this frequency. The expected width of the HI line is 10 km/s translating to about 48 kHz at 1400 MHz. So we would desire a channel width of about $48/4 = \sim 12$ kHz. For a channel width of 12 kHz, the total bandwidth you can observe is $(12 \text{ kHz} \times 128) = 1.5 \text{ MHz}$. Now you have two choices - either observe with 1 MHz or 2 MHz. Suppose you want a velocity coverage of ~ 200 km/s which translates to about 0.95 MHz. Thus, if you observe with a 1 MHz bandwidth at 1400 MHz, you should be able to get your desired velocity coverage and also the desired channel width. Having decided on your basebandwidth, lets try to determine the LO1 and LO4 required by your observations. You can use an IF bandwidth of 6 MHz (the lowest available).

You have determined your central frequency (1420.505 MHz) and your baseband bandwidth (1 MHz). Using these you have to find out the local oscillator settings. Let's use the default LO1 < RF. Then you want 1420.005 MHz in spectral channel 1 and 1421.005 in channel 128. Using **tune** will give you values of LO1 and LO4. Let's try to do the calculation here. For LO1 < RF, RF = LO1 + LO4. The default setting for LO4 is 70 MHz so let's assume that LO4 = 70 MHz. This gives a LO1 = $1420.005 - 70 = 1350.005$. However since LO1 is allowed only in steps of 5 MHz, we can only set 1350 MHz and the 0.005 has to be taken care of in LO4. Thus LO4 = 1350 MHz. Now recalling that

$$\text{RF} = \text{LO1} + \text{LO4};$$

$$\text{LO4} = 1420.005 - 1350.0 = 70.005 \text{ MHz}.$$

This will ensure that your HI line falls in the center of the USB. Thus you have obtained your **tpa** as under, **tpa** 1420.005 1420.005 1350 1350 70.005 70.005 For 1 MHz baseband, CLK_SEL = 4.

The frequently used baseband bandwidths at GMRT are given in Table 4. It is advisable to use the narrowest IF bandwidth possible so as avoid RFI corrupting the data. For an observing run of 9 hours with all 30 antennas and 128 channels in the USB, you will end up with a filesize of > 2 GB. The data backup facility at GMRT (Section 6.4) includes several 4mm dat tape drives for 24 GB dat tapes.

4.2 Bypass mode of 1420 MHz

A bypass mode is available for the L band so that the entire ~ 500 MHz bandwidth can be accessed. This mode allows one to access frequencies ranging from 850 MHz to 1500 MHz and without choosing each sub-bands (each sub-band is centred at 1060, 1170, 1280 and 1390 MHz with a bandwidth of 120 MHz). It is generally advised that while accessing the higher end of the frequency, you set the $LO1 > RF$ and for the lower frequency end set $LO4 < RF$. This prevents the image band corrupting your band of interest. Although this allows you to use cover a larger bandwidth, it may corrupt your data from local radio frequency interference.

4.3 Dual frequency observations

You also may want to observe simultaneously at two frequencies. This is possible only at 233 and 610 MHz frequencies.

You would need to edit the SETUPNEW.TXT file as follows (instead one can just say `cdsetd` on the unix-prompt):

```
here onwards, all settings for the first channel is for 610 and
second channel is for 235 MHz band. Watch on the settings like
attenuator, LO, IF etc for these two channels.
```

```
* this is a SETUPNEW.TXT file
```

```
* FRONT END PARAMETERS. Give 1420 only for full 1420 band selection.
```

```
*select freq. of observation (50/150/235/325/610/1060/1170/1280/1390/1420MHz.)
```

```
610
```

```
235
```

```
* select solar attenuator (0/14/30/44 dB. -1 for FE Termination.)
```

```
0
```

```
14
```

```
* select polarisation unswapped(0) or swapped(1)
```

```
0
```

```
* select cal-noise level.(E-HI(0)/HI(1)/MED(2)/LO(3) (-1 for RF OFF).)
```

```
0
```

```
* LO PARAMETERS. * select LO freq.(100 - 1600 MHz.)
```

```
680
```

```
310
```

```
* IF PARAMETERS. (Default is 14 14)
```

```
* select pre_attenuator & post_gain for CH1.(0,2,4,...,30 dB)
```

```
12
```

12.3

```
* select pre_attenuator & post_gain for CH2.(0,2,4,...,30 dB)
18
18.5

* select IF band width for CH1 & CH2 resp.(6/16/32 MHz).
32
32

* select ALC OFF(0) or ON(1). for CH1 and CH2
1
1

* New parameters being added :
* enter NG in time domain (0,25,50 or 100) percent duty-cycle
0

* enter Walsh Enable(1) or Disable(0)
0

* Select the Walsh Group : Low Group(0) or Highr Group(1)
0

* BASEBAND PARAMETERS ( set_para[16] onwards ):
* Select the antenna group :
* [0  if all ant bb mentioned below  ]
* [1  if (C0 , C1 , C2 , C3 :130 MHz)]
* [2  if (C0 , C1 , C2 , C3 :175 MHz)]
* [3  if (C4 , C5 , C6 , C8 :130 MHz)]
* [4  if (C4 , C5 , C6 , C8 :175 MHz)]
* [5  if (C9 , C10, C11, C12 :130 MHz)]
* [6  if (C9 , C10, C11, C12 :175 MHz)]
* [7  if (C13, C14, SP1, SP2 :130 MHz)]
* [8  if (C13, C14, SP1, SP2 :175 MHz)]
* [13 if (W1 , W2 , W3 , W4 :130 MHz)]
* [10 if (W1 , W2 , W3 , W4 :175 MHz)]
* [11 if (W5 , W6 , E2 , E3 :130 MHz)]
* [12 if (W5 , W6 , E2 , E3 :175 MHz)]
0

* Select Base BANDWIDTH in KHz (16000/8000/4000/2000/1000/500/250/125/62)
16000

* Select BB Gain                ( 0/ 3/ 6/ 9/ 12/ 15/ 18/ 21/ 24)
0
```

```
* Select BBL0 (Hz) Synth # 1 Freq.(MHz) (50.0 <= L0 <= 90.0 , step 100Hz)
66.0000
```

```
* Select BBL0 (Hz) Synth # 2 Freq.(MHz) (50.0 <= L0 <= 90.0 , step 100Hz)

66.0000
```

```
* Select Map for BB L0 Synthesizer
```

```
*   Chan  # 1   Chan  # 2
```

```
* 1 -   Synth # 1   Synth # 1
* 2 -   Synth # 2   Synth # 2
* 3 -   Synth # 1   Synth # 2
* 4 -   Synth # 2   Synth # 1
3
```

Now run

```
>setdlo
>setdif
>setdrf
```

etc.

tpa to be given is 614 244 680 310 66 66.

Record 64 channels (needs to be mentioned in `corrsys.hdr` file and look at the band-shape from the `showband.tcl` programme; 0,63,1). Check with `MATMON` and also check `DASSTAT` window.

After the observation you can convert your data in FITS using *gvfits*. Use the “gvfits” programme as follows:

```
astro1> listscan /rawdata/7jun/01TST01_OBJ.lta
astro1> vi 01TST01_OBJ.log
astro1> gvfits 01TST01_OBJ.log
```

For examples, editing `01TST01_OBJ.log` suggests to keep one of the stokes, say `RR` (also important is to choose normalisation/unnormalisation !). The output ‘TEST.FITS’ would correspond to one of the frequency data (614 MHz) and re-run “gvfits” for the other stokes (*i.e.* `LL`, 240 MHz) data.

4.4 Default parameters

The default settings used for continuum observations for the GMRT frequency bands in terms of RF, LO1, LO4 frequency settings, Solar Attn (in dB) and IF, BB bandwidths (all in MHz), ALC Status are shown in the Table 9.

Freq band	Solar Attn	RF_130 RR	RF_175 LL	LO1_130 RR	LO1_175 LL	LO4_130 RR	LO4_175 LL	IF BW	BB BW	ALC
150	14	157	157	223	223	66	66	6	8	ON
235	14	244	244	310	310	66	66	6	8	ON
325	0	325	325	255	255	70	70	32	16	ON
610	0	610	610	540	540	70	70	32	16	ON
1060	0	1060	1060	990	990	70	70	32	16	ON
1170	0	1170	1170	1100	1100	70	70	32	16	ON
1280	0	1280	1280	1210	1210	70	70	32	16	ON
1390	0	1390	1390	1320	1320	70	70	32	16	ON
dual	0-14	614	244	680	310	66	66	32-6	8	ON

Table 9: Default settings used for continuum observations for the GMRT frequency bands.

Part III

While Observing

5 During the Observations

The information which has previously been obtained during the preparation (Section 4) stage is now brought to and applied during observations. Aside from the source file and the command file which the user must prepare in advance, the other information can be provided to the telescope operators (“observers”) during set-up. It is the user’s responsibility to ensure that the observational set-up is correct, however, so it is important to monitor and check each step of the set-up and observing operations.

There are several other files, at this point, of which the user should be aware and which the telescope operator will edit according to user specifications.

One file is called `setupnew.txt` which sets up the hardware. Specified in this file are the observing frequency, front end parameters, the 1st LO, the IF bandwidth and the final baseband bandwidth (see also Section 2).

The other file of interest to the user is the `corrsys.hdr` file. This file contains the LTA (Section 4) value and channel selection.

The user should also check that the ALC (Section 2) switches are on.

As the telescope operator sets up the session, the user should particularly check the command, *e.g.* `tpa 1418 1418 1350 1350 68 68`. This specifies the sky frequency for both polarisations (1st and 2nd numbers), the 1st LO frequency for both polarisations (3rd and 4th numbers), and the 4th LO frequencies for both polarisations (5th and 6th numbers).

As the visibilities are recorded, the user should check on the amplitude of the signals from the calibrators. For self-correlations, the amplitudes should be, the correlation coefficients, i.e.

$$A = \frac{T_{\text{ant}}}{T_{\text{ant}} + T_{\text{sys}}}$$

where $T_{\text{ant}} = S \times G$; S , the source flux density (Jy), G , the gain (K/Jy) and T_{sys} the system temperature (K). Refer to Tables above in Section 4 for system values. These correlation coefficients are shown on the MATMON window (see Section 5.2.1–?? for examples of real-time display of cross-correlation outputs on a MATMON window).

Finally, information on troubleshooting is provided in the end (Appendix **Z3**).

5.1 Inputs to the operator in the GMRT Control Room

A file (via email or personally) with the following inputs:

From: Your Name

To: The GMRT control room

The settings are :

Source : OBJECT

```

ProjCode      : 01TST01
Phase Cal     : phas_cal
Flux Cal      : 3C48  (before the command file)
                : 3C147 (after the command file)

```

```

Command file : /odisk/gtac/cmd/yourname/yourname.cmd
Source list  : /odisk/gtac/source/yourname.list

```

Settings :

```

-----
BAND      = 1280 MHz
L01       = 1215 MHz
L04       = 74.6 MHz
IF        = 16 MHz
BB        = 1 MHz
CLK_SEL   = 4
tpa 1289.6 1289.6 1215 1215 74.6 74.6

```

Note:

Please observe 3C48 for 20m before the target source rises
and observe 3C147 for 20m after the target source sets.
Use LTA2=8m (for 16sec integration)

The CLK_SEL for various baseband frequencies are given in Table 4, it can also be found using

$$\text{baseband BW} = \frac{\text{samp\_freq}}{2}$$

and

$$\text{samp\_freq} = \frac{32}{2^{(\text{clk\_sel})}}.$$

5.2 Data quality and monitoring

The purpose of on-line data monitoring is to provide a running check on data integrity and proper operation of the system. User and operator interaction is limited to selecting the type and options of the display appropriate to the data being collected plus some scroll-back through the most recent displays.

Although, the telescope operators are fairly helpful during the observations and knowledgeable, it is the user who is responsible for ensuring that the observations run smoothly and correctly. The telescope operator is responsible only for seeing that the data are collected with apparently functioning equipment. The observer is responsible for the ultimate quality of the data, its calibration, and so on.

The displays (say for USB) that have proved useful so far to review the recent history of system temperature, gain, and total power level. A few of these are outlined below.

5.2.1 Total Power:

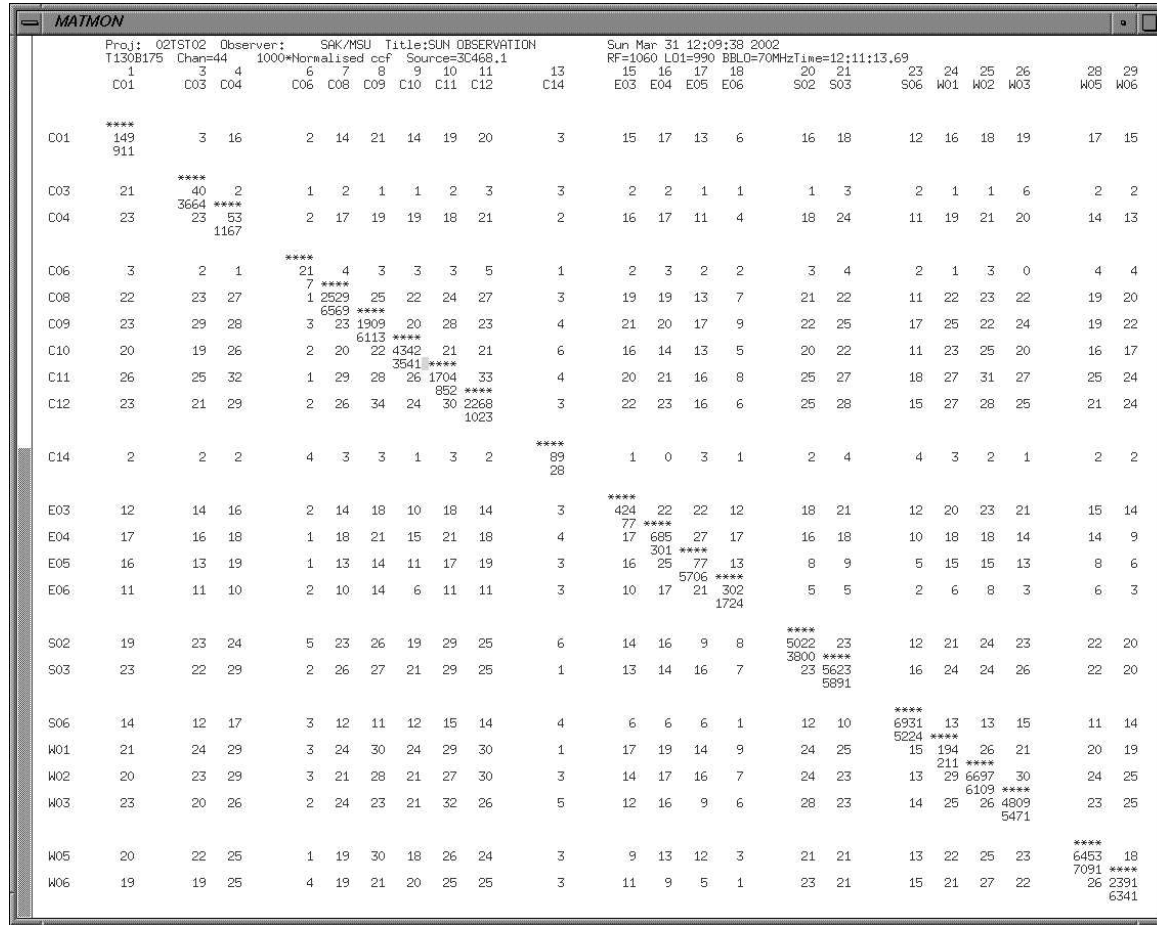


Figure 2: An example of many unhealthy antennas. The values along the diagonal show the values of the self-correlation-coefficients, the upper-triangular-half show the cross-correlation-coefficients for the 130 MHz channel and lower-triangular-half show the cross-correlation-coefficients for the 175 MHz channel.

The total power (or system temperature, when ALC is off) is the single most important diagnostic of the status of the observations. It contains information on everything from elevation to interference to the weather. Display of total receiver power or system temperature is useful for all types of observing.

Several software are available to examine the data in the lta format. Some of them are discussed below:

1. **dasmon** The monitoring needed for continuum observations are largely given by the **dasmon**. **dasmon** is a snapshot mode of getting a quick health check of the

system at a particular time. Following Figures (2, 3 and 4) gives examples of available healthy and poor antennas.

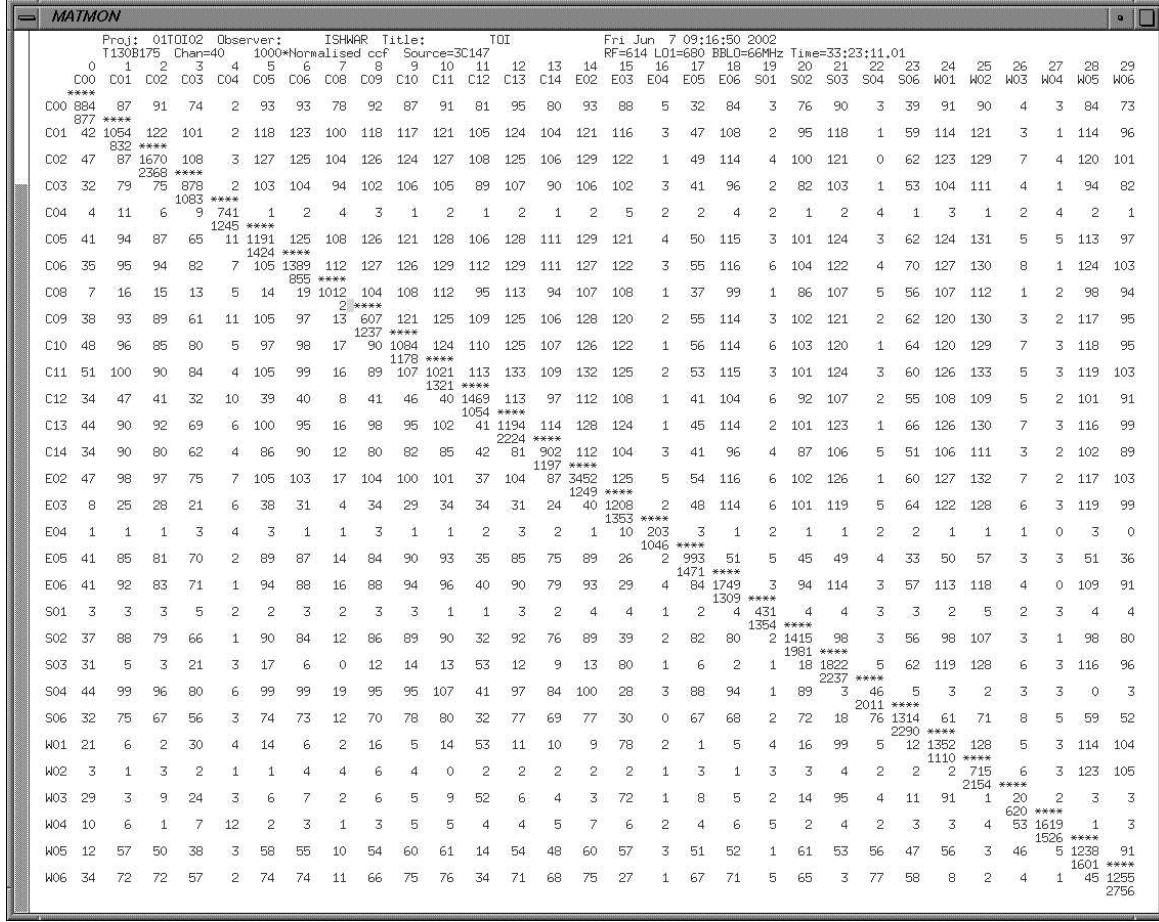


Figure 3: An example of a few unhealthy antennas.

The sensitivity in the total power mode would be

$$T_{\text{total power}} \propto \frac{2 k T_{\text{sys}}}{A \sqrt{\Delta \nu \tau}}$$

and in interferometric mode would be

$$T_{\text{interferometric}} \propto \frac{k (T_{\text{sys}} T'_{\text{sys}})^{1/2}}{2 (A A')^{1/2} \sqrt{\Delta \nu \tau}}.$$

Where T_{sys} & T'_{sys} are respectively the system temperatures of the two antennas, and A & A' are the corresponding effective areas of them.

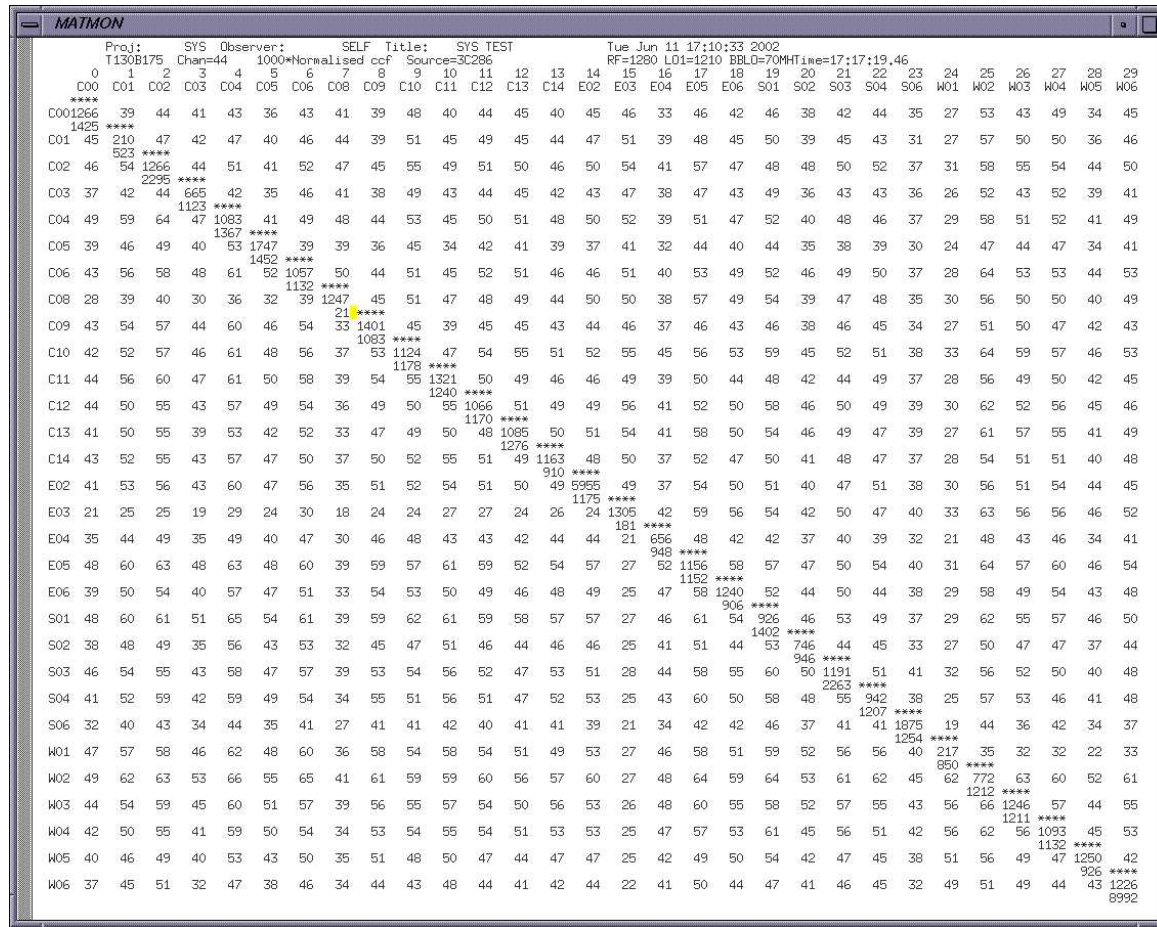


Figure 4: An example of all healthy antenna.

Cross-correlation functions displayed on the **dasmon** (Figures 2, 3 and 4) are given by

$$ccf \propto \frac{S_{(\text{in Jy})} \times K}{T_{\text{sys}}}, \quad \text{where } K \text{ is sensitivity and is in K/Jy;}$$

with some scaling factor (usually 1000).

Each Figure shows the following: (i) the diagonal elements are the self-correlation-coefficients, (ii) the upper-half elements are the 130 MHz channel cross-correlation-coefficients and (iii) the lower-half elements are the 175 MHz channel cross-correlation-coefficients. Explanations for a few examples of **dasmon** outputs is given below:

- (a) Figure 2: Antennas C02, C05, C13, E01, S01 S05 and W04 were not available for observations (see empty rows and columns corresponding to these antennas in the Figure 2). The observations were made on source 3C468.1 (project 01TST01) at a frequency of 1060 MHz.

- (b) Figure 3: Here all the antennas were used for the observations. The C04, E04, S01, W03 and W04 were down at both polarisations, whereas S04 and W02 (may be W01 as well !) was down in one polarisation only (either 130 or 175 MHz). The observations were made on source 3C147 source.
- (c) Figure 4: Something that an astronomer would love to see. This is an example where all antennas are healthy. User should compare the cross-correlation shown in this figure (Figure 4) with the one that is theoretically expected using above relation.

dasmon also allows (see Figure 5 below) the user to continuously monitor the amplitude and phase of the source being observed. For the sophisticated user, this is fairly useful in determining the stability of amplitude and/or phase. *i.e.* especially during scintillation and fringe winding.

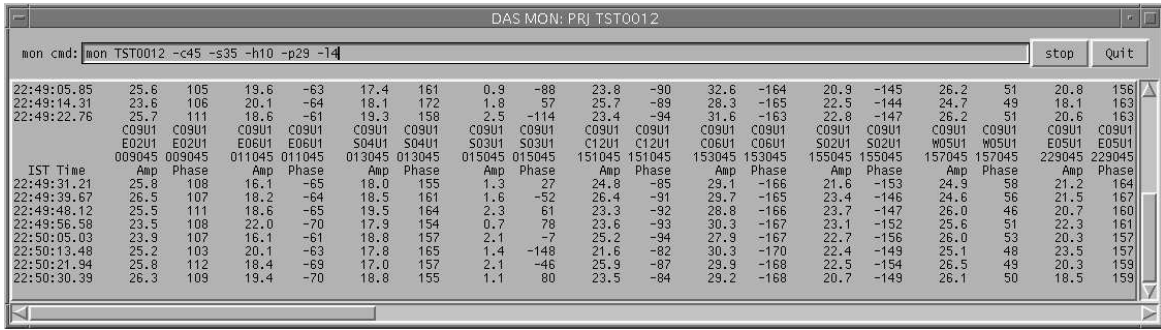


Figure 5: An example of the ‘mon.tcl’ display.

2. ondisp

Task ‘ondisp’ (see Figure 6) allows a user to keep track of antennas which are in healthy state. Each antenna shows a ‘flag’ associated with it. A few of the key ‘flags’ means as follows:

t : time out	Z : slewing
b : brake	B : azimuth brake
w : wind	m : mcm (monitor & control module) time out

3. tax

Task to extract data from a GMRT LTA file, with optional averaging in time and selection on time, baselines, frequency channels and on scans via the object name and/or scan number.

```
{astro0}> tax
tax> in      = /rawdata/8jun/01TST01.lta
tax> scans   = 0,1,2
```

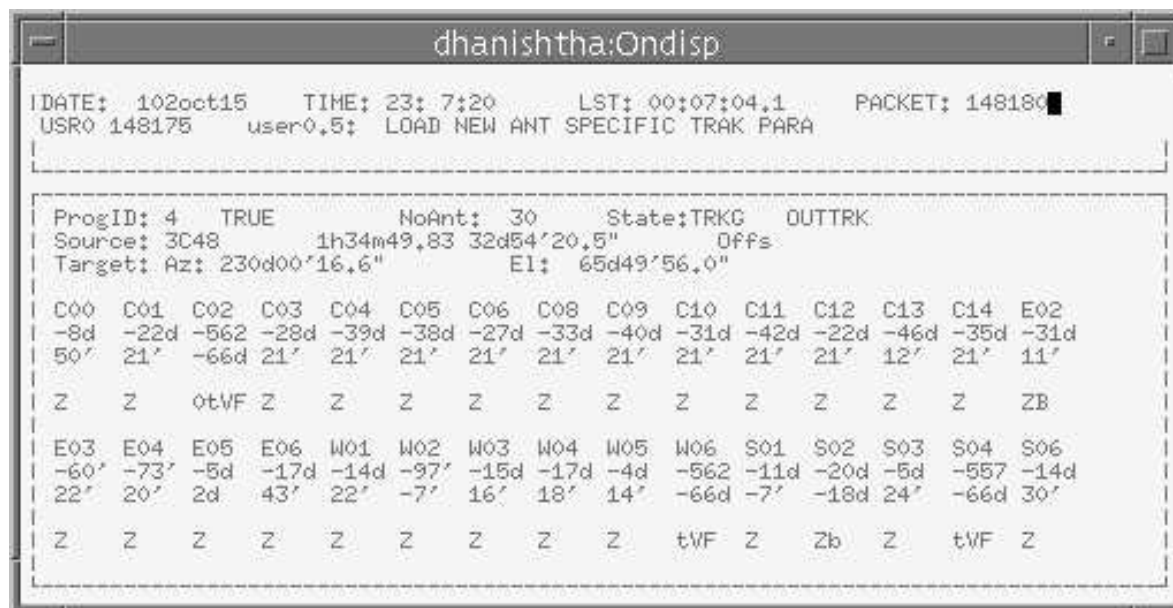


Figure 6: An example of the ‘ondisp’ display.

```
tax> object      =
tax> timestamps  =
tax> baselines   = C00
tax> channels    = 20
tax> antennas    =
tax> integtime   =
tax> normalize   =
tax> fmt         = ist%10.5f;base{chan{a%11.4f;p%8.1f}};\n
tax> go
```

extracts the scans 0, 1, 2 of the ‘01TST01.lta’.

OR

```
{astro0}> tax
tax> in          = /rawdata/8jun/01TST01.lta
tax> scans       =
tax> object      = 3C147|3C286
tax> timestamps  =
tax> baselines   = C00
tax> channels    = 20
tax> antennas    =
tax> integtime   =
tax> normalize   =
tax> fmt         = ist%10.5f;base{chan{a%11.4f;p%8.1f}};\n
```

tax> go

would extract all scans of the two sources, 3C147 and 3C129.

You can also run **explain** and know more about it's usage. For example, **tax** can also display your data (bandpasses, scans, etc...) from 01TST01.lta file. Some of **tax** outputs are shown in the following Figures. For example:

Figure 7: Stokes RR bandshapes of C01 & E05 and W01 & W05;

Figure 8: Stokes LL bandshapes of C03 & C05 E02 & W06 and S04;

Figure 9: Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351–018 respectively) on baselines C00 & C01 and E02, E03 & W06;

Figure 10: Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351–018 respectively) on baselines S02, S03 & S06 and W03, W05 & W06.

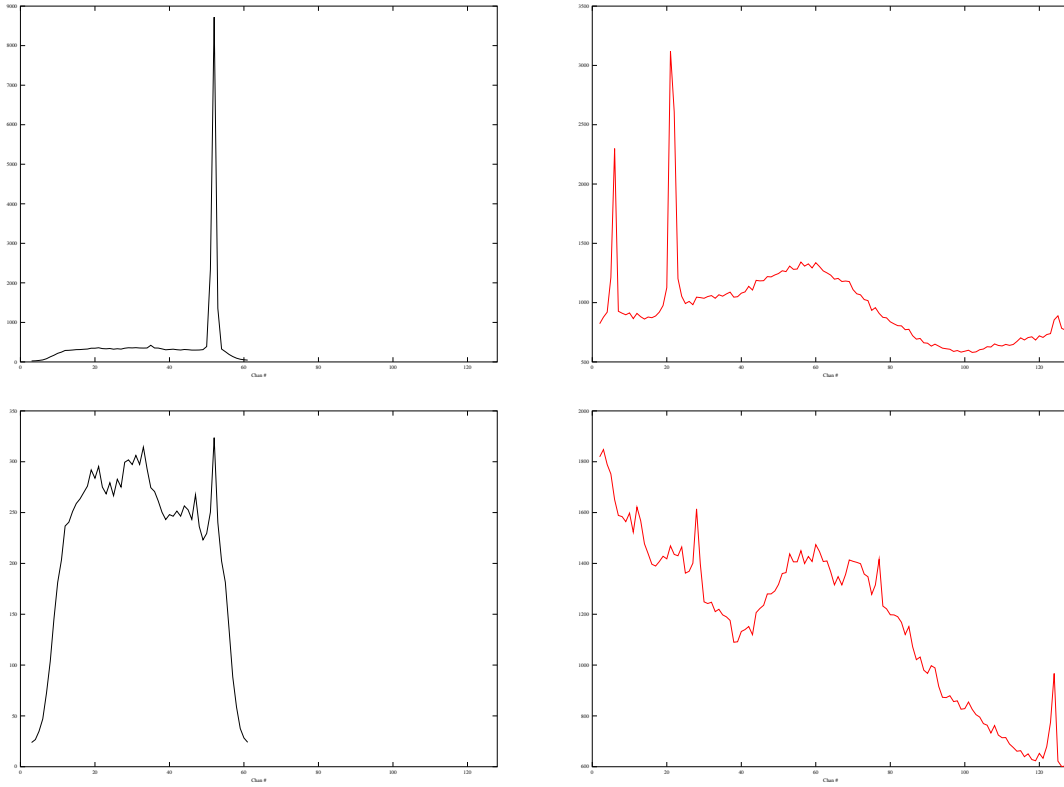


Figure 7: Stokes RR bandshapes of C01 & E05 (top two) and W01 & W05 (bottom two), the spikes seen is an effect of RFIs.

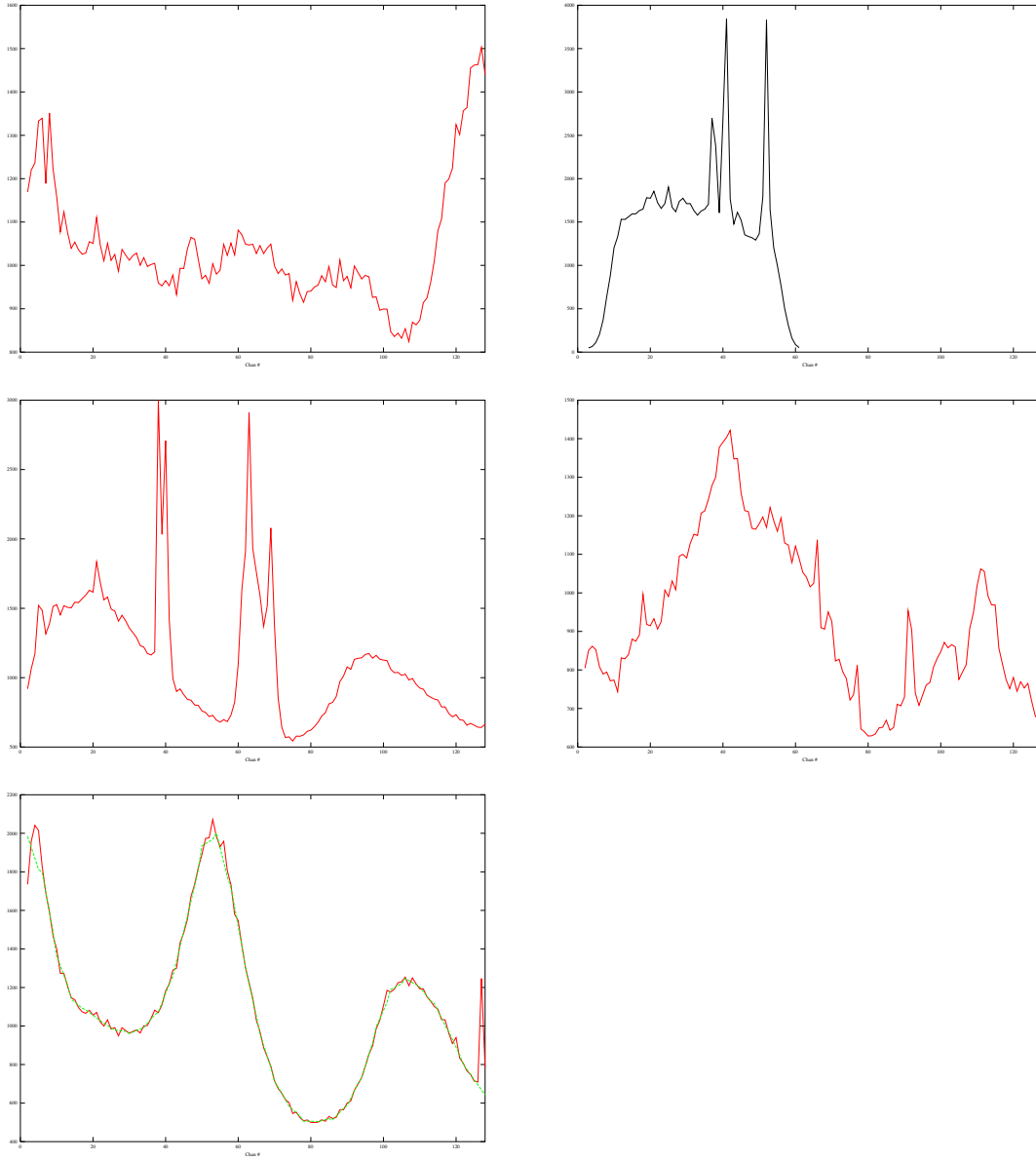


Figure 8: Stokes LL bandshapes of C03 & C05 (top two), E02 & W06 (middle two) and S04 (bottom one). In S04, the FLAGing (`1taflag`) programme has removed the spikes and the bandshape is fitted with a polynomial.

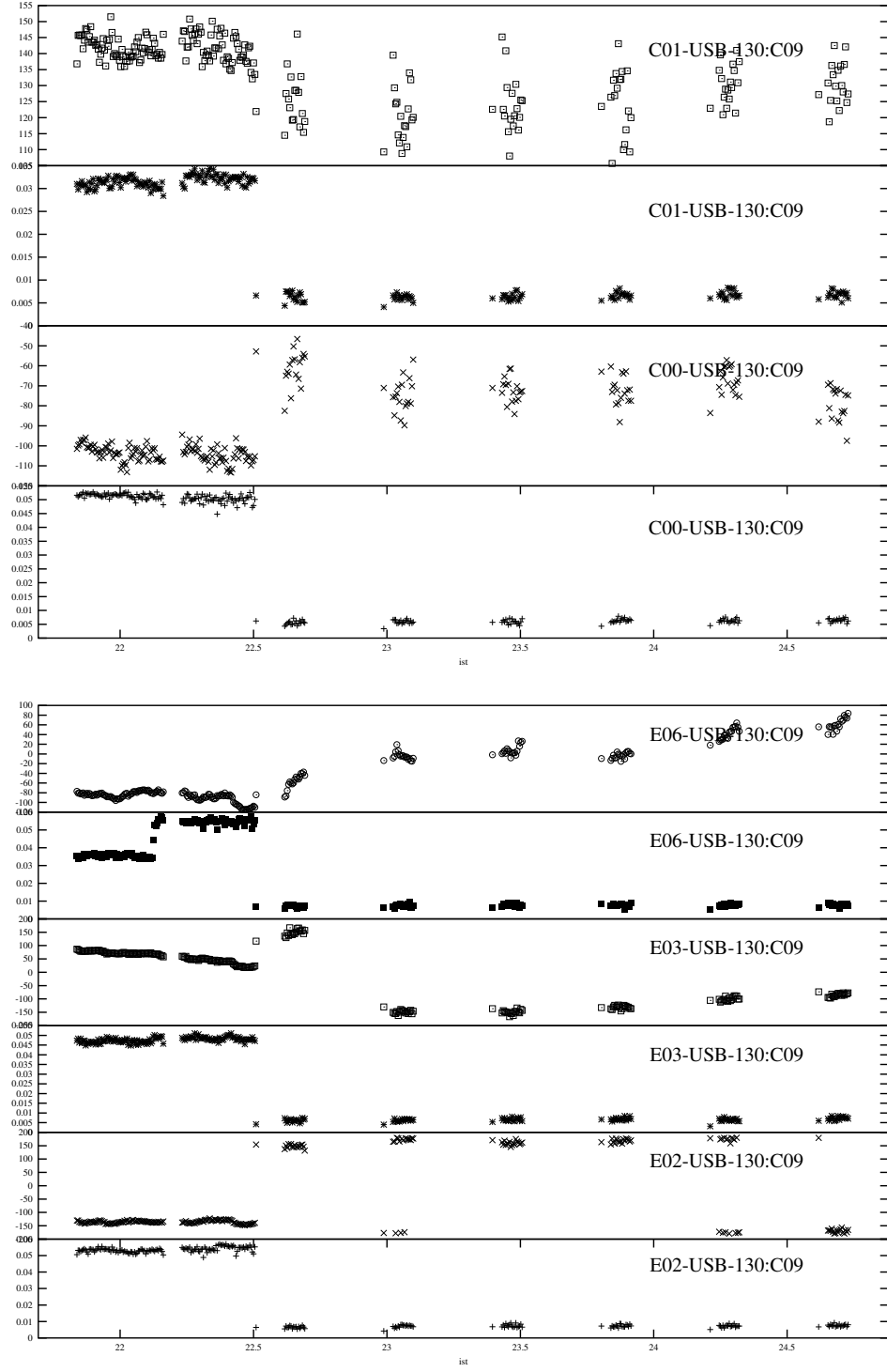


Figure 9: Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351–018 respectively) on baselines C00 & C01 (upper) and E02, E03 & W06 (lower). C09 being the reference antenna, amplitude is in arbitrary units.

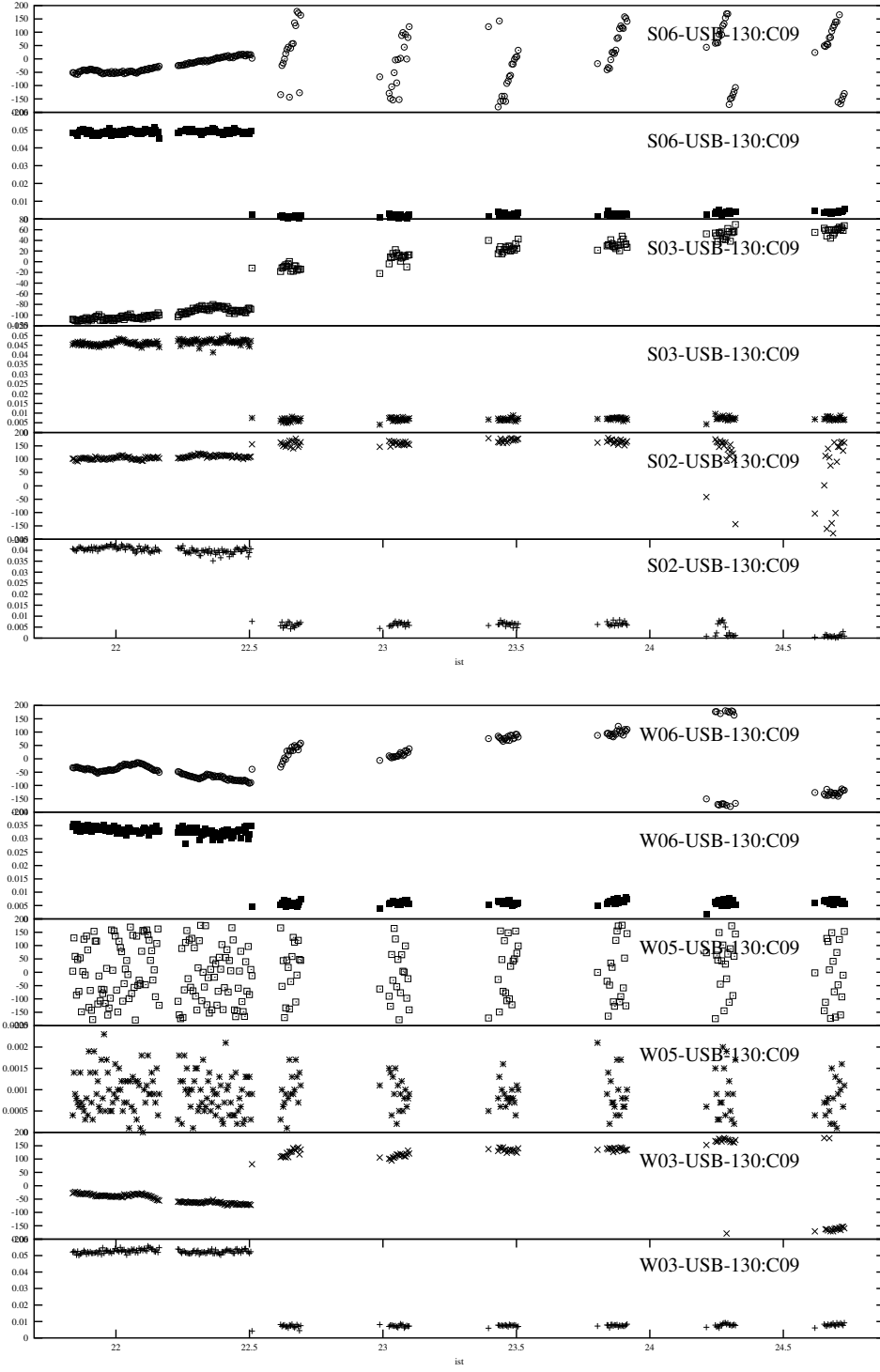


Figure 10: Amplitude and phases of Primary (first scan) and secondary (later scans) calibrators, (3C286, 1351–018 respectively) on baselines S02, S03 & S06 (upper) and W03, W05 & W06 (lower). C09 being the reference antenna, amplitude is in arbitrary units.

Part IV

After Observing

6 Your data

Data collected on a particular date are collected into the directory, *e.g.* ‘/rawdata(1)/date’ (the disk is mounted on mithuna/b is visible from all other PCs). These data are in LTA format and will have an extension of ‘*.lta(b)’ on the filename. A variety of softwares are available for examining these data in this format. (See GMRT home-page → Observing Help → offline data analysis software.).

The most useful for on-site diagnostics is `xtract/tax`. To run most of this software, the user must first type, `source /astro/RC.csh` (or `source /astro/RC`). The same software is also available at the NCRA and is sourced in the same way. The programme, `ltacomb` is useful to concatenate multiple files and the programme `gvfits` is required to convert the data into FITS format for later reading into the Astronomical Image Processing System (AIPS) of the NRAO.

Spectral line observers who wish to make Doppler corrections can run `dopset` (again “`source /astro/RC`”).

Within AIPS, the user will first have to run `INDXR` (and it may also be necessary to run `UVSRT`). Even for the continuum observations, a bandpass calibration is required, so the user should proceed with data reductions as for a spectral line data set and then average the channels later (using `SPLAT` or `SPLIT`). Since there is no CHANNEL 0 data set for initial calibration, one possibility (for a sufficiently strong calibrator) is to first calibrate in time on a single channel and then to apply this calibration when determining a bandpass solution.

6.1 Interference Monitoring

Spectrum analyser in the receiver room shows two kinds of outputs: (1) output from the optical fibre displaying 130 and 175 MHz channels and (2) the baseband output displaying the USBs and LSBs. The spectrum analyser output from optical fibre is shown in the Figure 11.

6.2 Running AIPS at the GMRT

Machines `astro1`, `astro2`, `astro3`, `astro4` are generally available for the observers on priority basis. Please get visitors login and passwd from the local-system-administrator on these machines (Aniruddha B. Adoni and/or Mangesh Umbarje). You would use ‘/analysis/yourname/’ as your working data area on any one of them. Your data on mithuna machine (‘/rawdata/6jun/yourfile.lta’) is visible on all other machines at the GMRT. You also have to ‘`source /astro/RC.csh`’ or ‘`source /astro/RC`’, if you wish to use local packages (*e.g.* `gvfits`, `tax`, etc ...).

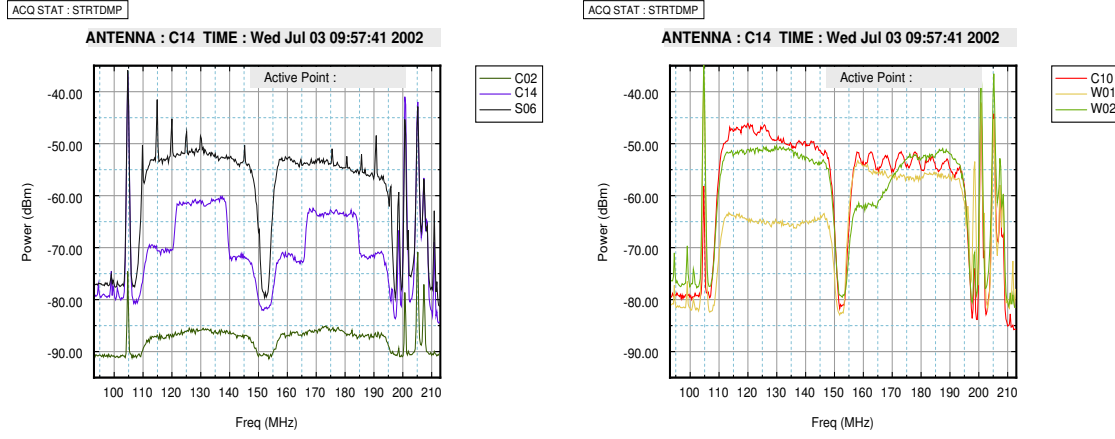


Figure 11: Spectrum analyser output from optical fibre for a few of the antennas, each plot showing 130 and 175 MHz. S06 (in left Figure) shows spikes (RFIs) in both channels.

6.3 Primary Beam Gain Correction

Coefficients to use in the task PBCOR in AIPS for primary beam correction of GMRT data are tabulated here. The polynomial fit to the beam is $1 + (a/10^3)x^2 + (b/10^7)x^4 + (c/10^{10})x^6 + (d/10^{13})x^8$ where x is in terms of (separation from pointing position in arcmin * frequency in GHz). a, b, c, d are the coefficients which are required to be specified in PBCOR when using GMRT data. PBPARM(3) (=a), PBPARM(4) (=b), PBPARM(5) (=c), PBPARM(6) (=d). PBPARM(7)=0 for GMRT. More information can be found at <http://www.ncra.tifr.res.in/~ngk/primarybeam/beam.html>.

Freq band	PBPARM(3)	PBPARM(4)	PBPARM(5)	PBPARM(6)	Halfpower width
153 MHz	-4.04	76.2	-68.8	22.03	180'
235 MHz	-3.366	46.159	-29.963	7.529	118.5'
325 MHz	-3.397	47.192	-30.931	7.803	85.2'
610 MHz	-3.486	47.749	-35.203	10.399	44.4'
L band	-2.27961	21.4611	-9.7929	1.80153	26.2' (1280 MHz)

Table 10: Primary Beam Gain Correction.

6.3.1 Running AIPS on your data

If you are combining data from both the sidebands first run `ltamerge` to create combined datafile using the following commands :

```
astro1> ltamerge -i InputLtbFile -I InputLtaFile
```

This would create file `ltamerge_out.lta`.

Then run `gvfits` (it provides UV data in J2000 epoch); to use `gvfits` you first need to run the program `listscan` to create “log” and “plan” files. Edit the “log” file to select normalization type, a subset of the data etc. Finally run `gvfits` on the edited log file. *e.g.*

```
astro1> listscan /rawdata/7jun/01TST01_OBJ.lta
astro1> vi 01TST01_OBJ.log
astro1> gvfits 01TST01_OBJ.log
```

This makes an output file “TEST.FITS”. `gvfits` will not work on any files that have been processed by offline programmes (*e.g.* `ltacleanup`, `tmac`). This is because these programmes delete elements of the header that `gvfits` needs.

Start AIPS using following commands :

```
astro1> newgrp aips
astro1> source /usr/aips/LOGIN.SH (for bash shell)
astro1> source /usr/aips/LOGIN.CSH (for csh/tcsh shell)
astro1> aips
```

Begin `START_AIPS` and load this file (`01TST01.FITS`) into AIPS using `FITLD` task and follow your favourite way of reducing the data.

The `logflags` files can be used as an input in `gvfits` to flag bad data reported by ONLINE, while your observations were made.

6.4 Backing your DATA

The data backup facility at GMRT (Section 6.4) includes several 4mm dat tape drives for 24 GB dat tapes (DDS3). These machines with corresponding tape drive (DAT-tape-drive or Exabyte tape drive) are as follows:

<code>/dev/nst1</code>	—	astro1 machine	(4-mm DAT-tape drive)
<code>/dev/nst0</code>	—	astro2 machine	(4-mm DAT-tape drive)
<code>/dev/rmt/3hn</code>	—	chitra machine	(8-mm Exabyte-tape drive)

Also you can also copy your LTA files (`/rawdata/7jun/01TST01_lta` or `01TST01.FITS`) using DAT-tape-trive on mithuna machine.

<code>/dev/nst0</code>	—	mithuna machine	(4-mm DAT-tape drive)
<code>/dev/nst1</code>	—	mithuna machine	(4-mm DAT-tape drive)

6.5 Your observation log

The observation log will be e-mailed to the respective user after his/her observations.

6.6 Computer Facilities at the GMRT

- There are many computers placed in terminal room for astronomical data analysis specifically reserved for GTAC observer. (also see GMRT Home-page → Facilities → Computers)
- Kindly get the relevant account name and password from System Administrator at GMRT, Khodad. Or check in the Control Room, GMRT for the same.
- In the terminal room, a network printer is available called 'npgcc'. From a linux machine, command to print is: `lpr -Pnpgcc [files]` or `lpr [files]`.
- Default data area to get observation files is /rawdata for USB data & /rawdata1 for LSB data. In this area data will be present in the subdirectory called by day and month e.g. 17may.
- Offline analysis software developed are available. For any path confusion, always source /etc/bashrc for bash and /etc/csh.cshrc or /etc/cshrc (whichever exists) for csh (or 'source /astro/RC' for bash shell or 'source /astro/RC.csh' for csh/tcsh shell). Run the software and say explain. This will give help for the software's usage. At present following software utilities exist: (also see GMRT home-page → Observing Help → Offline data analysis software).
 1. xtract : Extract data from lta file in variuos formats.
 2. tax : Graphical interface to plot the data extracted by 'xtract'.
 3. listscan : List the scan in the ltafile for converting to FITS format.
 4. gvfits : Convert GMRT (lta) data to FITS format.
 5. ltahdr : Gives info about lta file, scan-wise.
 6. ltacomb : Concatenate number of lta files to one lta file.
- To use aips on these machine, after logging do following :
 1. newgrp aips
 2. source /usr/aips/LOGIN.CSH (for csh) or source /usr/aips/LOGIN.SH (for bash)
 3. aips
 4. Prefer to use aips id 1010, 1020 and 1030 on astro1, astro2 and astro3 respectively.
 5. There is /DATA partition kept for aips data purpose.
 6. Also, /analysis local disk space is available.
- **Important : No backup is taken for /DATA and /analysis area and user has to take his own backup before he leaves GMRT site. Data in this area will not be available after that more than a day.**
- **kindly note : DDS-3 tapes can be bought at GMRT.**

6.7 Computer Facilities at the NCRA

You can use the

(a) computing facilities at the NCRA for your data analysis, please contact V. Venkatasubramani (system administrator) or Shekhar Bachal for accessing visitor (GTAC) machines,

(b) many of the machines in the common computing facility are equipped with either DAT-tape (DDS3) drive to load and/or back-up your data.

Acknowledgements

This document involves inputs from several people, particularly those associated with the GMRT. We express our thanks to everyone of them.

Document updated on 4th July 2006 by Manisha Jangam & D.J. Saikia.

Appendix Z1. Feedback

Please provide us feedback by filling up the Observer/Visitor Feedback Form available at GMRT home-page.

All publications resulting from the GMRT data should have an acknowledgement of the form

"We thank the staff of the GMRT who have made these observations possible. GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research."

Appendix Z2. The input files

The source file: The following is the source file, specific example can be picked from ‘/odisk/gtac/source/yourname.list’.

3C286	13h28m49.66s	30d45'58.7"	1950.0
1637+626	16h37m55.31s	62d40'34.3"	1950.0
N6503	00h40m19.70s	+51d47'07.2"	1950.0
IS01	15h36m00.00s	50d00'00.0"	2000.0
NGC1097	02h46m19.0s	-30d16'28.0"	1950.0

The command file: The following is a simple command file. The consecutive numbers are NOT in the file itself, but are used for the explanation given here. The file observes a flux density calibrator, 3C286 for 30 minutes first, then a phase calibrator, 1637+626, and then enters a loop in which the phase calibrator and the source, N6503, are observed consecutively and continuously, with 10 minutes on the phase calibrator and 30 minutes on-source. In most cases, the first part of the observing session will not be run from this file but by issuing commands from the monitor, at least until the user is satisfied that both the flux density calibrator and the first part of a run on the phase calibrator are satisfactory. Running manually also allows the user to better determine how much slewing time is required between calibrators and source. If this is the case, then lines 5 to 23 of this file would be omitted and the resulting file implemented after the first scan of the phase calibrator is found to be okay. Note that there is no allowance in this file for a flux density calibration scan in the mid-point of the observations or at the end. In order to insert such observations, the user must manually stop this file and issue commands from the console. If the file is restarted, it will start from the beginning. There is also no end to the file, since the loop, once entered, has no graceful exit. The session will stop when commands are issued from the console to stop it. If the array reaches its altitude limit (i.e. the source sets) first, then it will continue to collect data as instructed in this file while pointing at blank sky at the array altitude limit (currently 17 degrees).

cmode 1	Specifies that times are relative, rather than absolute.
suba 4	Specifies the subarray being used.
addlist '/online/operator/source/yourname.list'	Ensures that the system can read the source list. This must be included in this file, even if already done manually at the console.
lnkndas	
gtsrc '3c286'	Gets and precesses the coordinates for the specified source.
goout	Specifies the track (outer or inner) on which slewing should occur. The choices are goout or goin. For sources in the northern part of the sky,

it's generally best to use goout.

gosacout As above, but required for the subarray controller.
The choices are gosacout and gosacin.

sndsacssrc(1,12h) Slew to the source and start tracking (1)
for up to 5 hours (5h).

time 5m Do not do anything for 5 minutes in order to allow the
array to reach its target.

strtndasc Start the correlator and collect data.

time 10m Continue to collect data for 10 minutes.

hold; stabct Release the brakes (hold) in case minor wind gusts
have resulted in the brakes being applied automatically
at some point during the observations. For
strong winds, an alarm will sound in the control
room. And set the time at the antenna based computer
(stabct).

time 10m Keep collecting data for another 10 minutes.

stpndasc Stop the correlator (i.e. stop collecting data).

stpsactrk Stop tracking.

gtsrc '1637+626' Get and precess coordinates for the second source,
here the phase calibrator.

goout

gosacout

sndsacssrc(1,5h)

time 6m

\$1 starts the loop

gtsrc '1637+626'

goout

gosacout

sndsacssrc(1,12h)

time 2m &

strtndasc

time 10m

stpndascan

stpsactrk

gtsrc 'N6503'

goout

gosacout

sndsacssrc(1,5h)

time 2m

strtndasc

time 10m

hold;stabct

time 10m

```
hold;stabct
time 10m
hold;stabct
stpndascan
go to 1          returns to the beginning of the loop.
end
```

A few examples of command files are shown below (each column is an independent command file):

```

cmode 1
addlist '/temp2/data/source/01TST1.list'
addlist '/temp2/data/source/01TST1.list'
lnkndas
suba 4
goout
gosacout
cp 0

gts '0237-23'
sndsacsrc(1,h)
time 0.5m
stbt
strtdasc
time 10.0m
stpndasc

gts '0213-132'
sndsacsrc(1,h)
time 1.5m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '0235-19'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '0240-00'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '0349-27'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '0403-13'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '0442-28'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

end

cmode 1
addlist '/temp2/data/source/01TST1.list'
lnkndas
suba 4
goout
gosacout
cp 0

gts '3C286'
sndsacsrc(1,h)
time 0.2m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '1323+32'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '1328+25'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '1350+31'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

gts '3C286'
sndsacsrc(1,h)
time 1.0m
sndsacsrc(1,h)
stbt
strtdasc
time 10.0m
stpndasc

end

cmode 1
lnkndas
subar 4
goout
gosacout

addlist '/temp2/data/source/vlcal.list'
addlist '/temp2/data/source/01TST1.list'

$1

gts '2139+143'
sndsacsrc(1,h)
time 0.5m
sndsacsrc(1,h)
stbt

strtdasc
time 5.0m
stpndasc

gts '2232+117'
sndsacsrc(1,h)
time 0.5m
sndsacsrc(1,h)
stbt

strtdasc
time 5.0m
stpndasc

gts '3C433'
sndsacsrc(1,h)
time 0.5m
sndsacsrc(1,h)
stbt

strtdasc
time 8m
hold;stbt
time 8m
hold;stbt
time 8m
hold;stbt
time 8m
stpndasc

goto 1
end

cmode 1
dellist 2
addlist '/temp2/data/source/01TST1.list'
lnkndasq
subar 4
goout
gosacout

$1

stpsactrk
gts '1035+564'
sndsacsrc(1,h)
time 1m
sndsacsrc(1,h)
stbt
strtdasc
time 10m
stpndasc

stpsactrk
gts '1116+517'
sndsacsrc(1,h)
time 1m
sndsacsrc(1,h)
stbt
strtdasc
time 10m
hold;stbt
time 10m
hold;stbt
time 10m
hold;stbt
stpndasc

goto 1
end

```

Appendix Z3. The trouble-shooting

The trouble-shooting

1. Fringes Disappeared ?
 - (a) stpdasc; gts 'srcname'; strtdasc
 - (b) are antennas tracking your source ? have they hit the azimuth limit ?
 - (c) is your source extended ?
 - (d) has any of correlator software crashed ?
 - (e) have the front-end parameters got reset ? ask the observer.
2. Fringes are winding ?
 - (a) check LO_1 and LO_4 settings.
 - (b) stpdasc; tparm, prjfreq, gts 'srcname'; strtdasc
 - (c) check time synchronisation between correlator PCs and ONLINE PC and GPS time.
 - (d) ionospheric variations ? The winding will be random.
3. Fstop window says 'link reset; packet transmission not possible'
 - (a) fstop has crashed.
4. Some baselines record low cross-correlation on a point source ?
 - (a) Is polarisation swap, required on some antennas, applied ?
 - (b) Are the self-correlations of problem antennas as expected ?
 - (c) Are pointing offsets being loaded ?
 - (d) stpdasc; gts 'srcname'; strtdasc
5. The LTA and AIPS file header shows RF=0 Hz, IF_LO=0 Hz, BB_LO=0 Hz ?
 - (a) If noticed during observations, stpdasc and stpdass and start again. Don't forget to set TPARM (Frequency parameters to correlator).
 - (b) If noticed after observations, forget about that data and get a fresh run.